An update on measurements with Si detectors irradiated to extreme fluences

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Introduction

Motivation

RD50 Prolongation Request: May 2018
5.2.2 Extreme fluences:
Explore the macroscopic device properties (I-V, C-V-f, CCE) on different p-type silicon materials up to fluence values ranging from **1e16 to 5e17 n_{eq} cm^{-2} and beyond** with neutrons and protons of different energies.

Previous work at 1e17 and above:

- G Kramberger et al., *Charge collection studies on custom silicon detectors irradiated up to* ***1.6E17 n_{eq}/cm^2,*** **2013 *JINST* 8 P08004**

- Marko Mikuž et al., *Silicon Sensors at Extreme Radiation Fluences,* AIDA2020 Topical Workshop on Future of Tracking, Oxford, April 2nd, 2019
  https://indico.cern.ch/event/781403/contributions/3314657/

- I. Mandić et al., *First measurements with silicon detectors irradiated above 3e17 n/cm^2*
  32nd RD50 Workshop, Hamburg, 2018
  https://indico.cern.ch/event/719814/contributions/3022499

Introduction

At extreme fluences:

- high leakage current
- low CCE
- large drop of carrier mobility
- …..

Marko Mikuž at AIDA2020 Topical Workshop on Future of Tracking, Oxford, April 2nd, 2019:

- Conclusion: *Low fluence extrapolations do not work at all !*

… go out and *measure* to get anything working at *extreme* fluences !!!

Introduction

- Continuation of the work presented at 32nd RD50 Workshop in Hamburg, 2018
  https://indico.cern.ch/event/719814/contributions/3022499

- new measurements will be presented in this contribution:

  ➔ charge collection with Sr-90 up to higher bias voltages

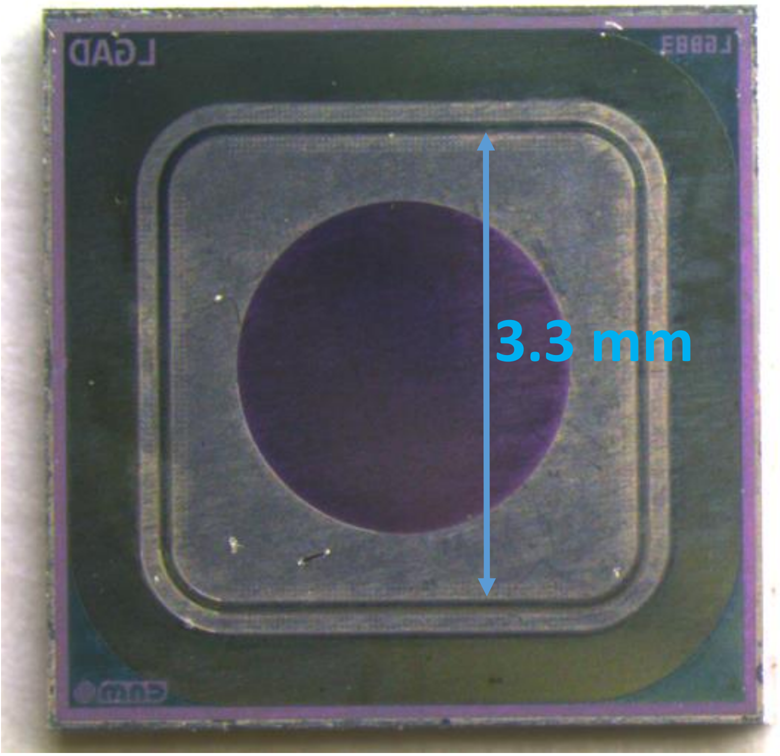
  - improved cooling – measurements at -30°C
  - adapt Ortec 142 amplifier (replaced bias resistor)

  ➔ E-TCT measurements

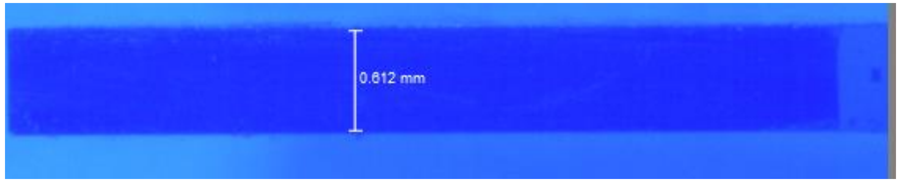
Samples

- CNM LGAD
- 50 µm epitaxial on Cz substrate (0.1 Ωcm)
- chip thickness ~ 600 µm

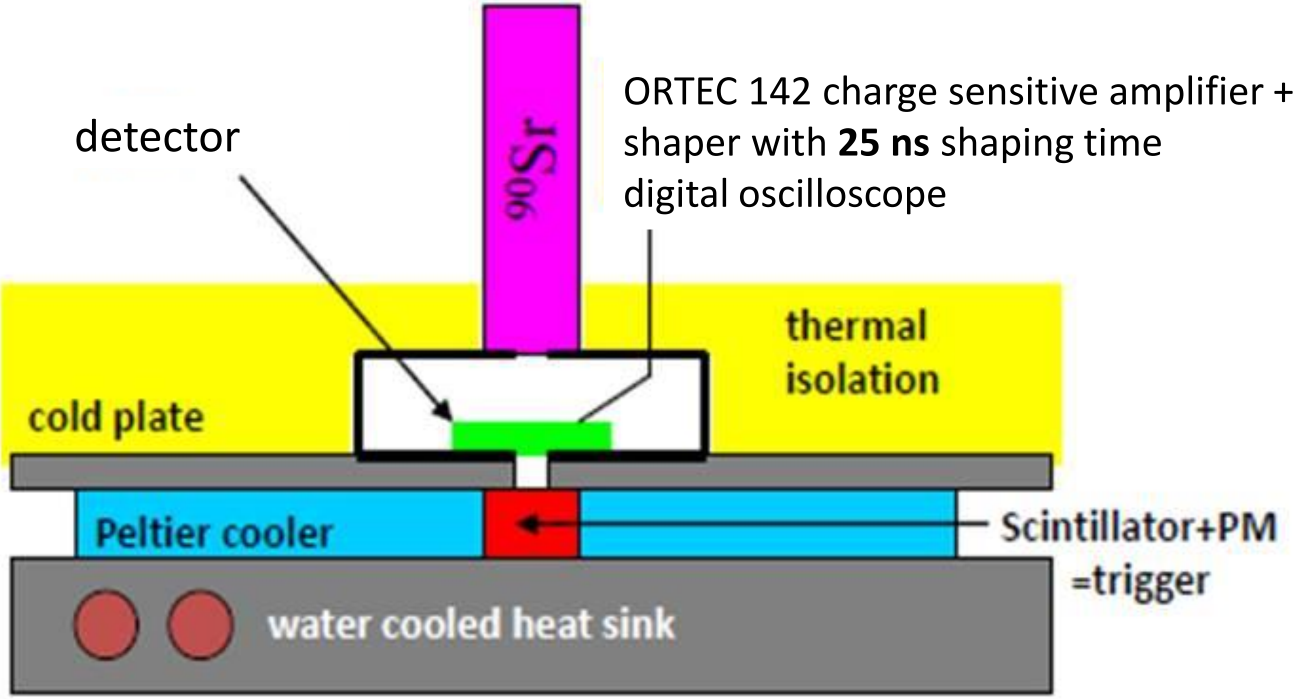
- Irradiated with reactor neutrons to **2.8e16**, **1e17** and **3e17 n/cm²**



Measurement of detector thickness → 612 µm



Charge Collection measurement with Sr-90

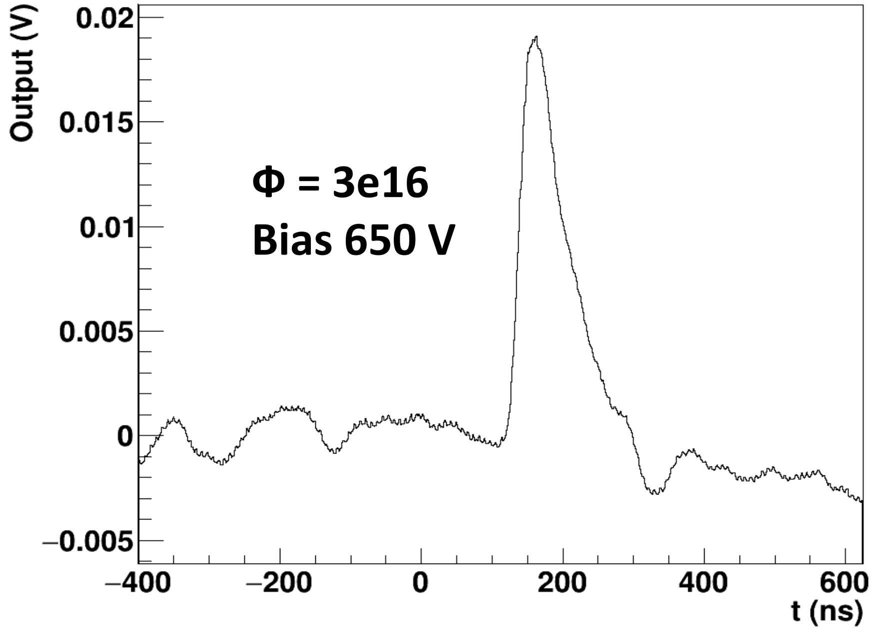


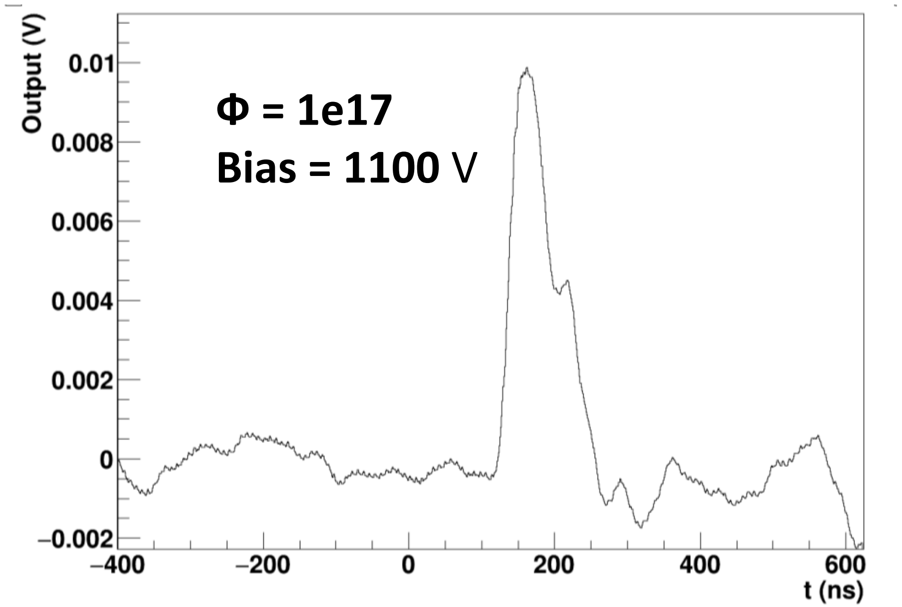
- Large (3x3 mm) pad detector and small collimator holes enable recording of a clean sample of waveforms
  ➔ no "empty triggers" → can measure average charge collected after passage of a (almost) MIP also at small signal/noise

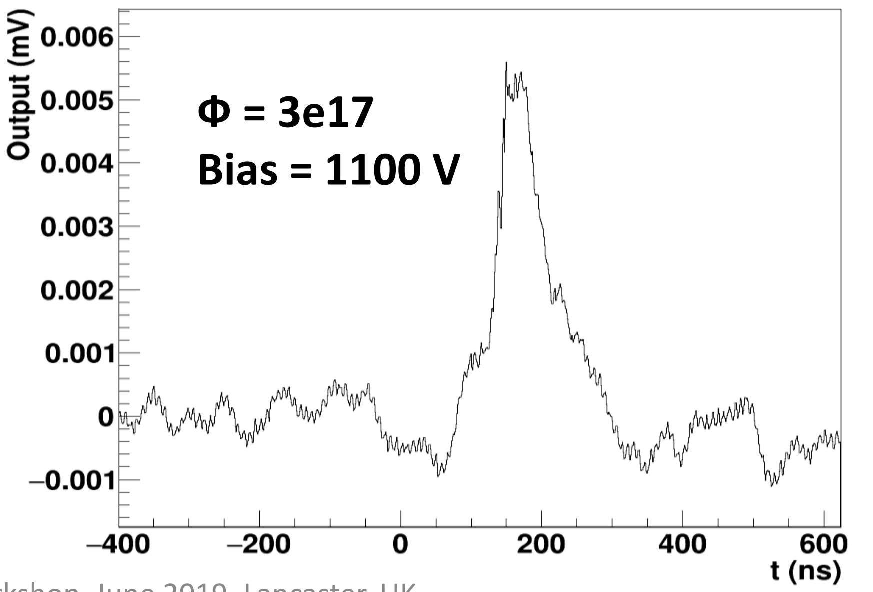
- New since last year: a) replaced bias resistor in ORTEC 142 ➔ 1 MΩ instead of 10 MΩ
  b) improved cooling (measure at -30 C)

  } Can measure up to higher bias voltages

Charge collection measurement with Sr-90



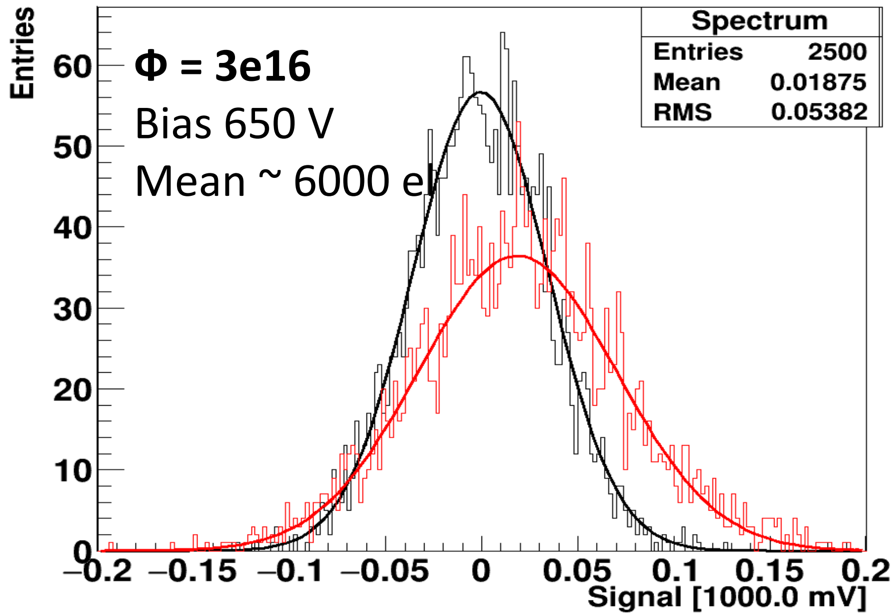


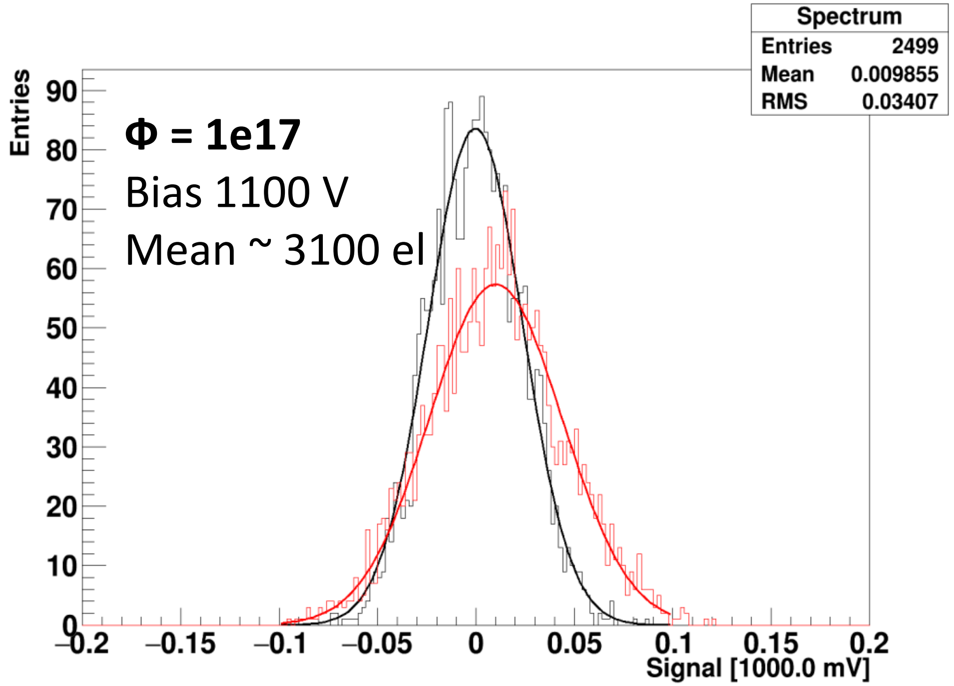


LGAD (50 um)
Average of 2500 waveforms at highest bias voltage

➔ MIP signal: sample at peak of the waveform(~ 160 ns)

Charge collection measurement with Sr-90



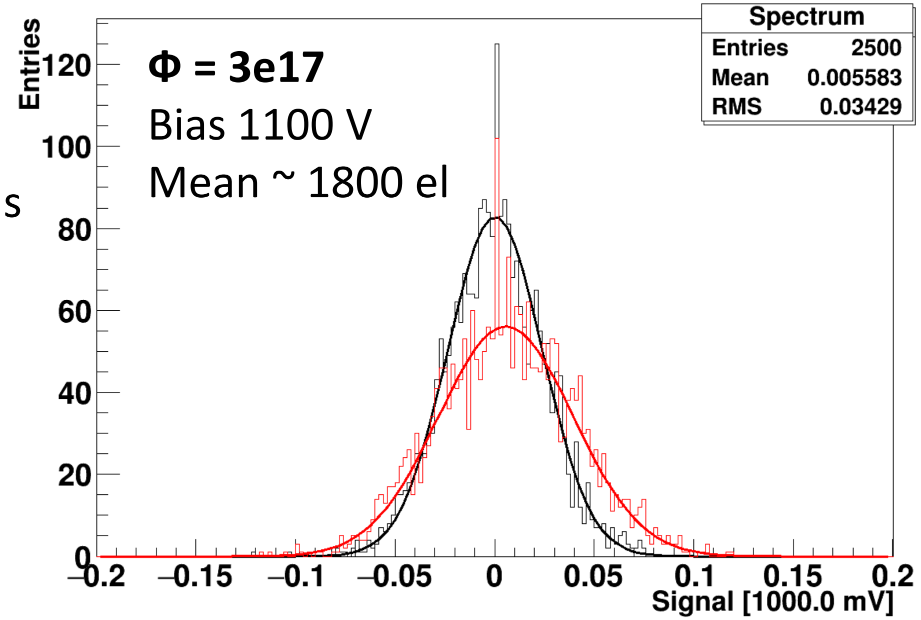


Spectra of values sampled at:

- Red (signal): 160 ns, peak of average waveform (see previous slide)
- Black (noise): -300 ns (noise)

➔ signal spectra shifted to the right compared to noise

➔ mean of the distribution ~ mean of collected charge



Charge collection measurement with Sr-90

G. Kramberger *et al,* 2013 *JINST* **8** P08004

"Magic formula" (300 um spaghetti Φ > 1e15):

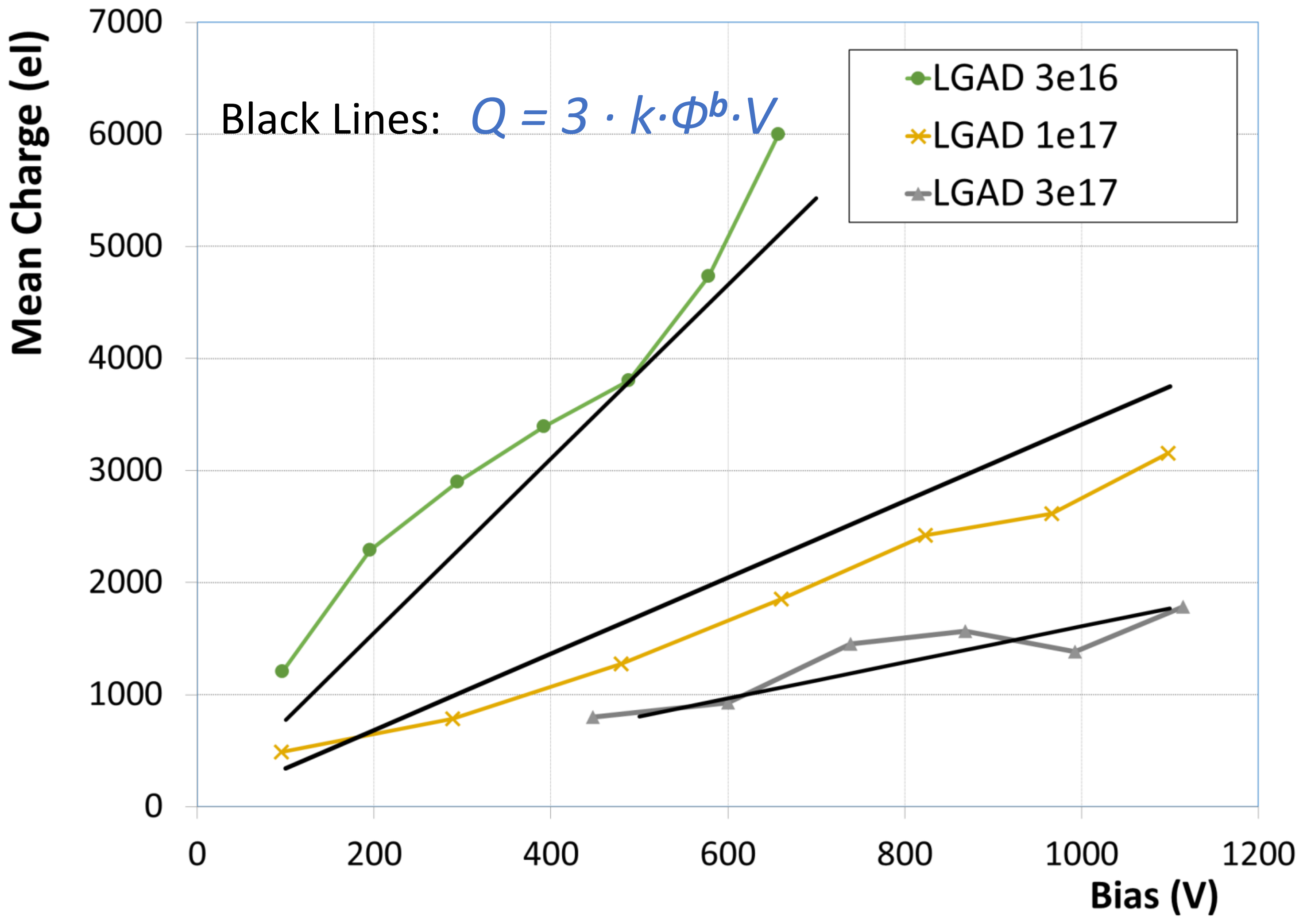
$$Q_{MPV} = k \cdot \Phi^{b} \cdot V,$$

k = 26.4 el/V, b = -0.683
Φ in 1e15 n/cm^2, V in volts

At high fluence, when drift distance short we can approximate:

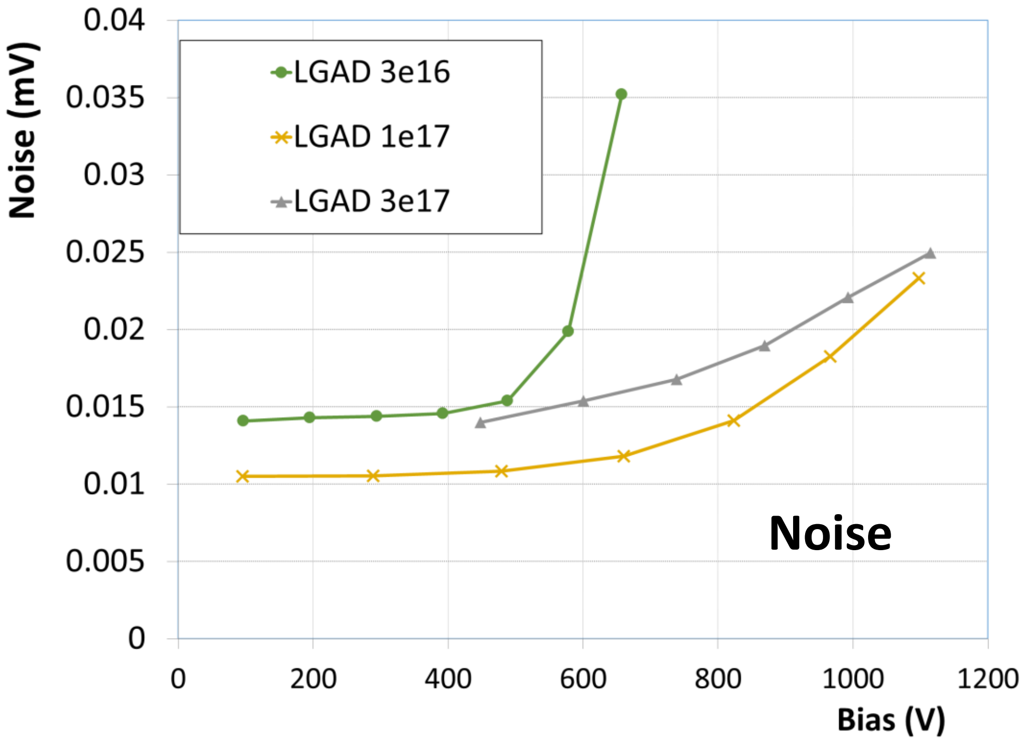
$$Q \sim (dq/dx \cdot D) \cdot (1/D) \cdot L,$$

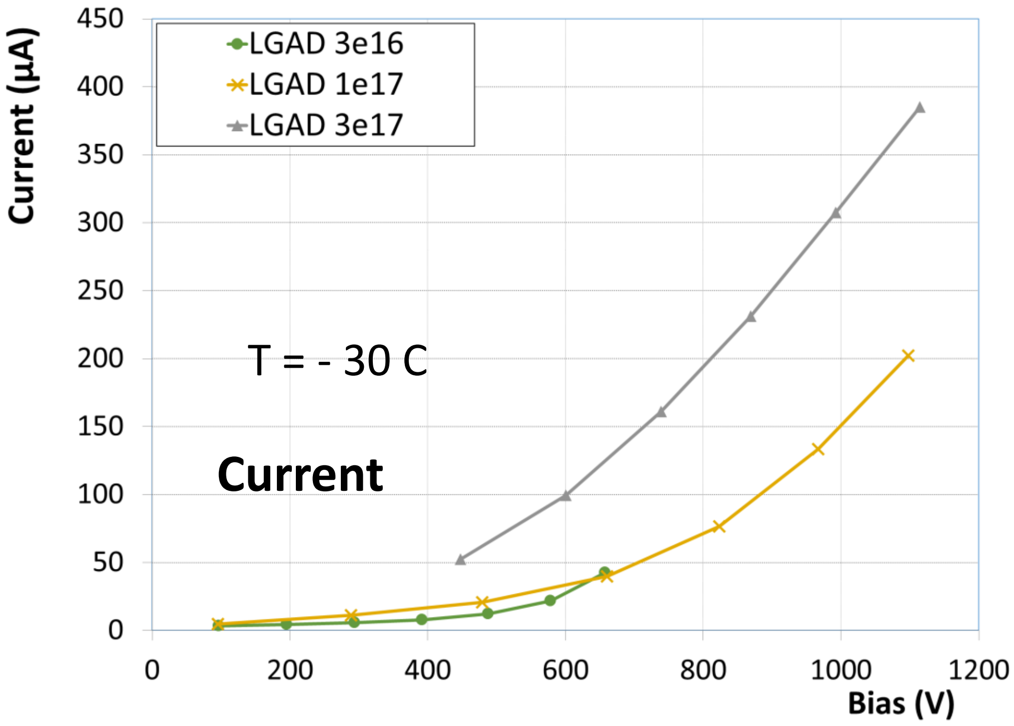
- D cancels
- $L = v \cdot \tau$, charge collection distance
- v increases with E (until saturation)
- at high Φ, saturation at higher V
- more charge multiplication because of higher E



➔ ~ 2.5 times more charge with 50 µm LGAD compared to 300 µm spaghetti

Charge Collection measurement with Sr-90



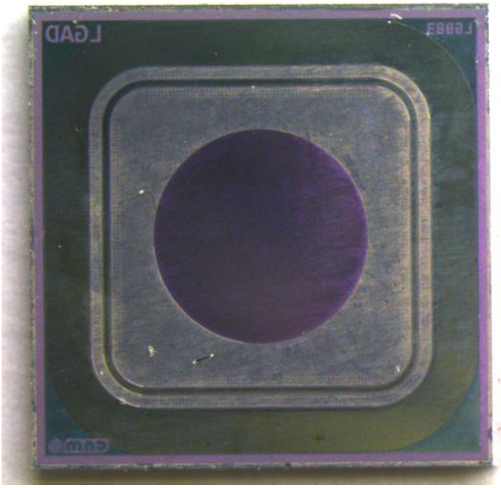


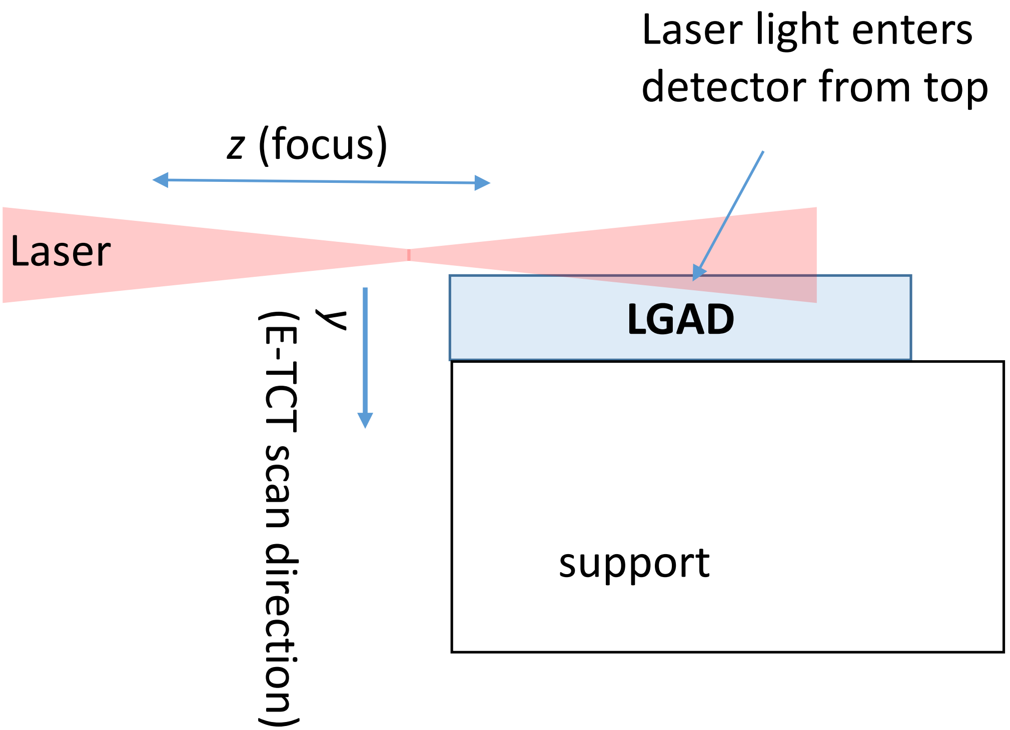
- sample 3e16 steep increase of noise above 500 V → multiplication (breakdown)
- 1e17 and 3e17 increase less steep

<u>Edge-TCT with pad detectors</u>

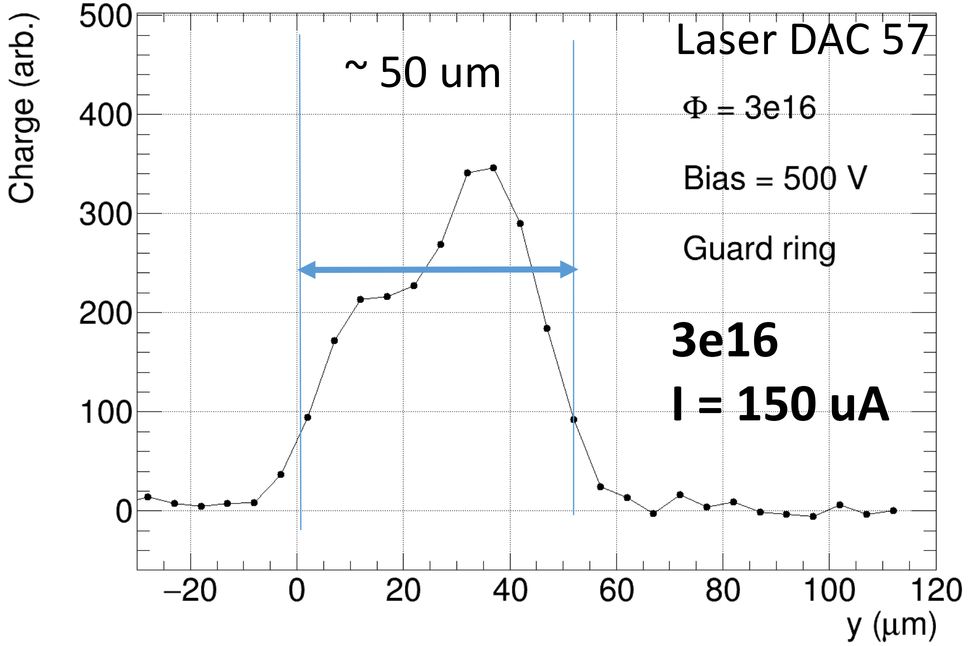
- 1000 V over 50 μm results in very high electric field
  ➔ high fluences: mobility drops -> impact ionization coefficient smaller
- what is the actual detector thickness?
  ➔ maybe there is a significant voltage drop over the substrate at these fluences
- <u>Check with E-TCT</u>
- difficult to measure E-TCT with pad detectors
  ➔ laser light enters the device also from top
  ➔ strange charge collection profiles

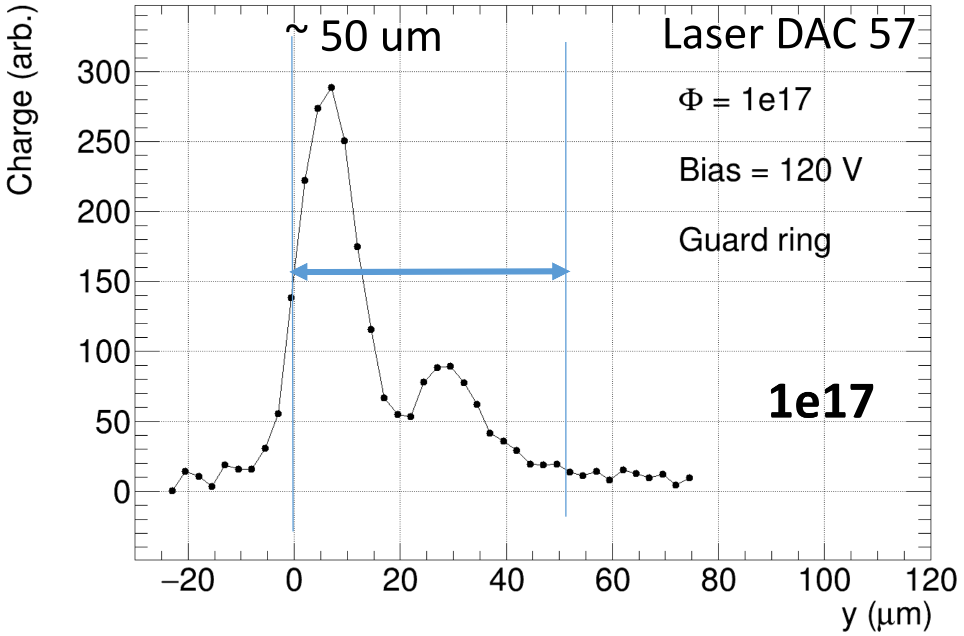
  ➔ simple solution: measure induced current on guard ring instead of pad main electrode (pad)
  → region of charge collection is better defined, focus can be set below the guard ring electrode

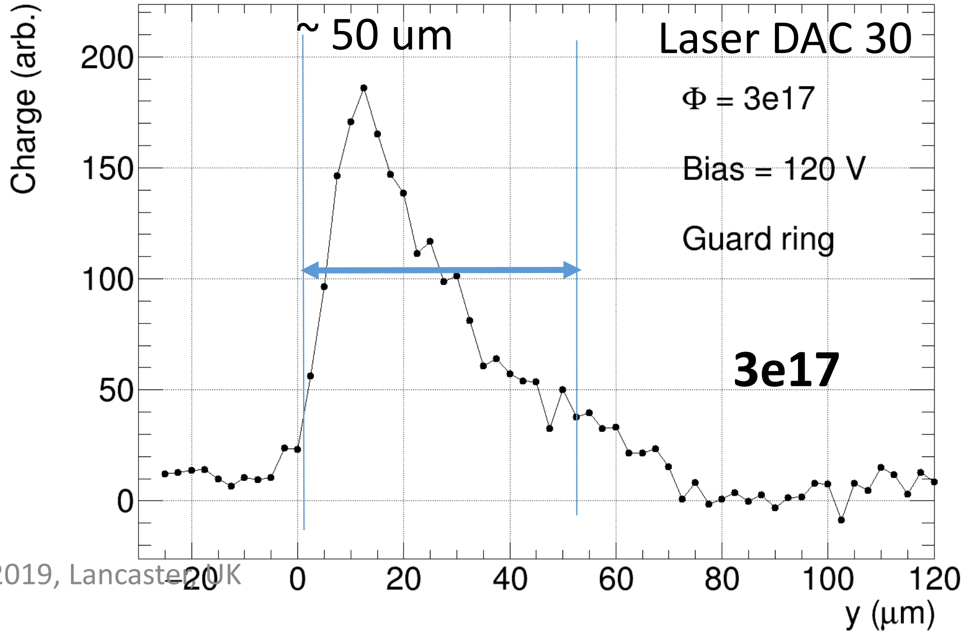




Edge-TCT with pad detectors







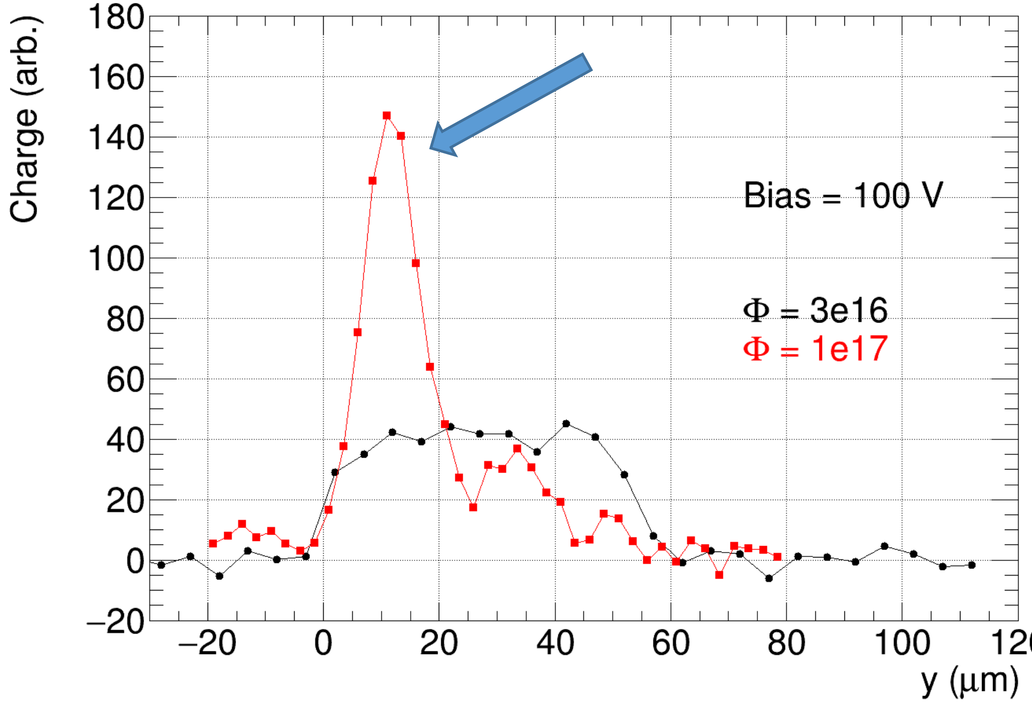
➔ It seems that charge is collected from top ~ 50 µm

➔ substrate sufficiently conductive so that electric field in the substrate (*y* > 50 µm) not high

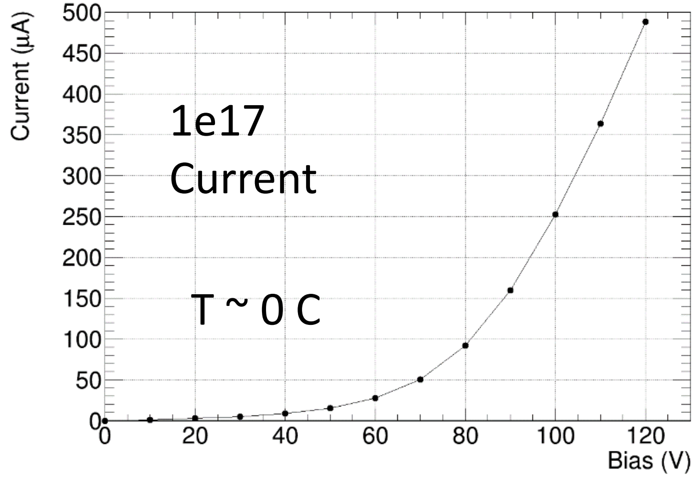
Edge-TCT with pad detectors

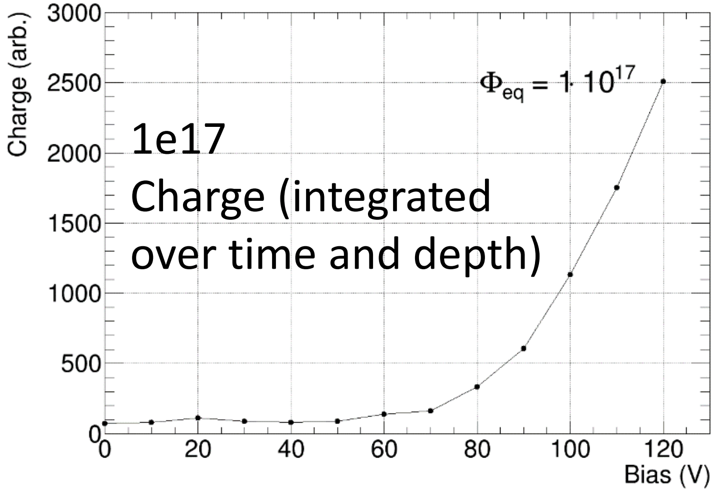
- Sample irradiated to 1e17: very high pulses when laser near the top electrode

→ looks like charge multiplication already at 100 V!



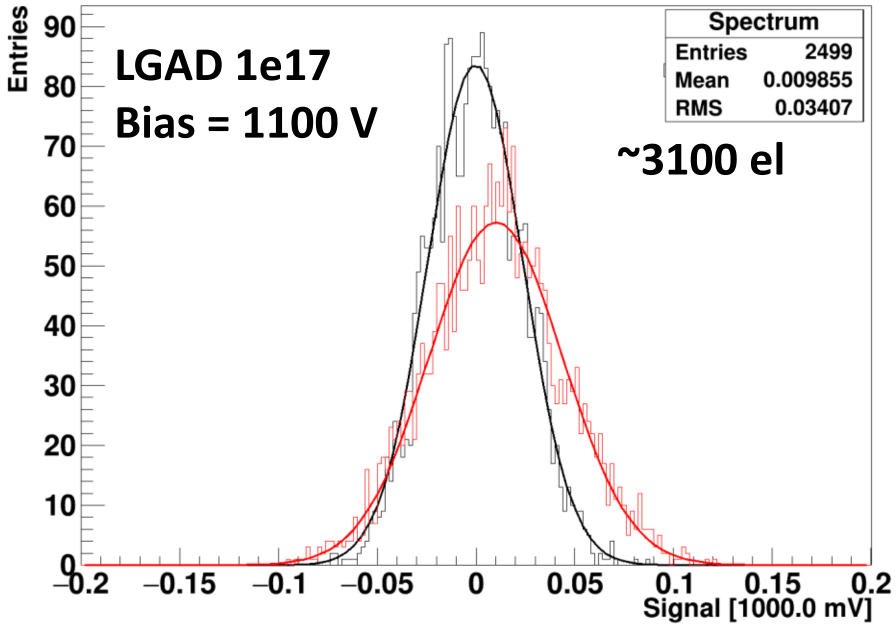
Current and charge similar voltage dependence:

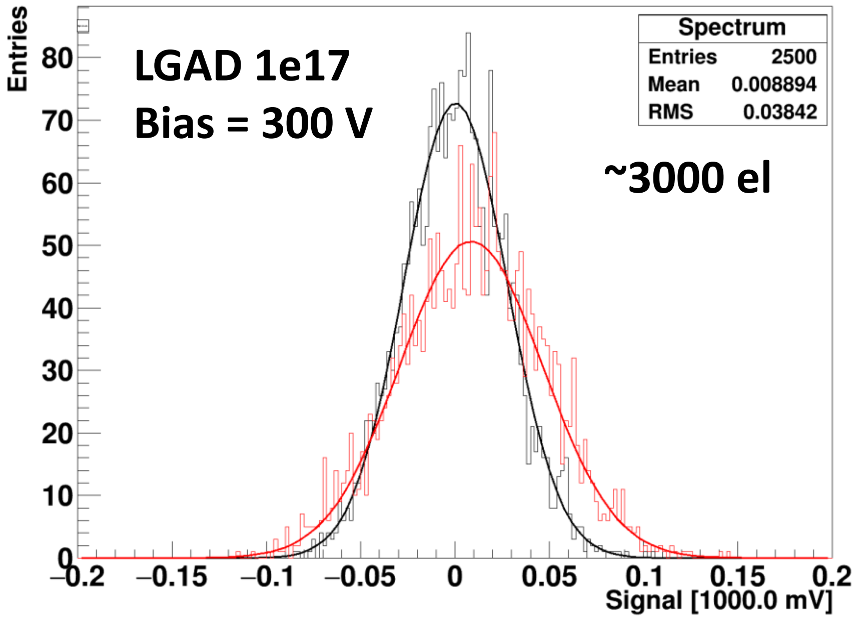




Note:
Initially this detector could be biased to 1000 V
→ high current observed after several measurements and after few weeks at RT

Charge collection measurement with Sr-90



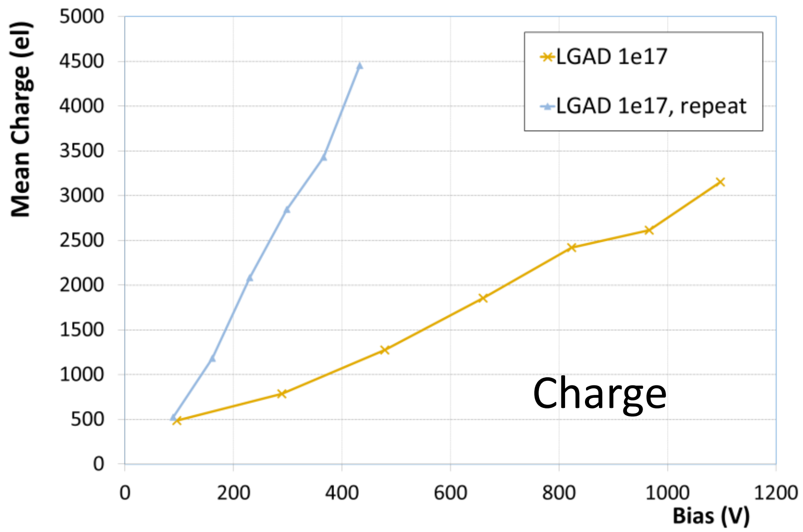


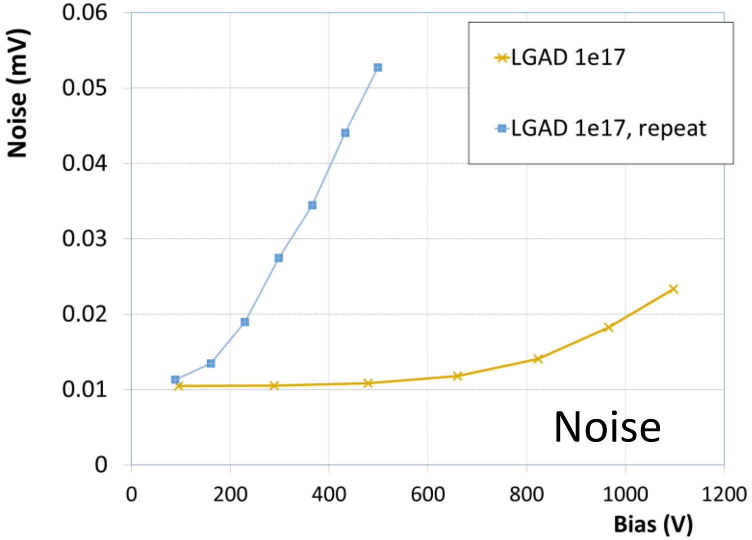
Same detector, measurements repeated after few weeks at RT

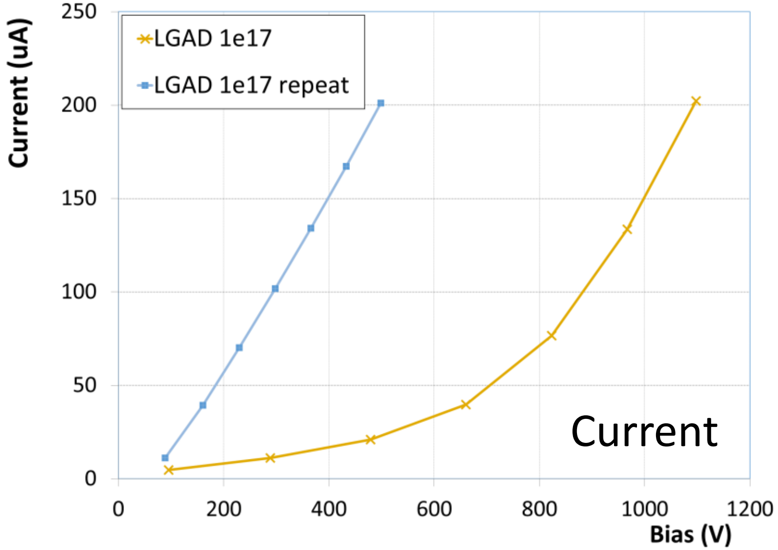
➔ same charge but at much lower bias voltage
➔ but also noise and current increased
→ charge multiplication at lower bias voltage

Charge collection measurement with Sr-90

- Detector irradiated to 1e17 changed behavior after few weeks at RT







Conclusions:

Charge collection:

- dependence of collected charge on fluence and bias bias voltage follows the "magic" formula up to 3e17

$$Q \propto \Phi^{b} \cdot V, \ (b = -0.683, \ \Phi \text{ in } 1e15 \text{ n/cm}^2, \ V \text{ in volts})$$

- more charge at same bias voltage collected with 50 µm thick detector compared to 300 µm:

  ➔ 50 µm : ~ **6000 el** at **3e16** at 650 V**,** ~ **3000 el** at **1e17** and ~ **1800 el** at **3e17** at 1100 V

- significant change in voltage dependence of collected charge observed for the sample irradiated to 1e17
  ➔ higher charge multiplication at much lower bias voltage
  ➔ transition after some time at RT

Edge TCT:

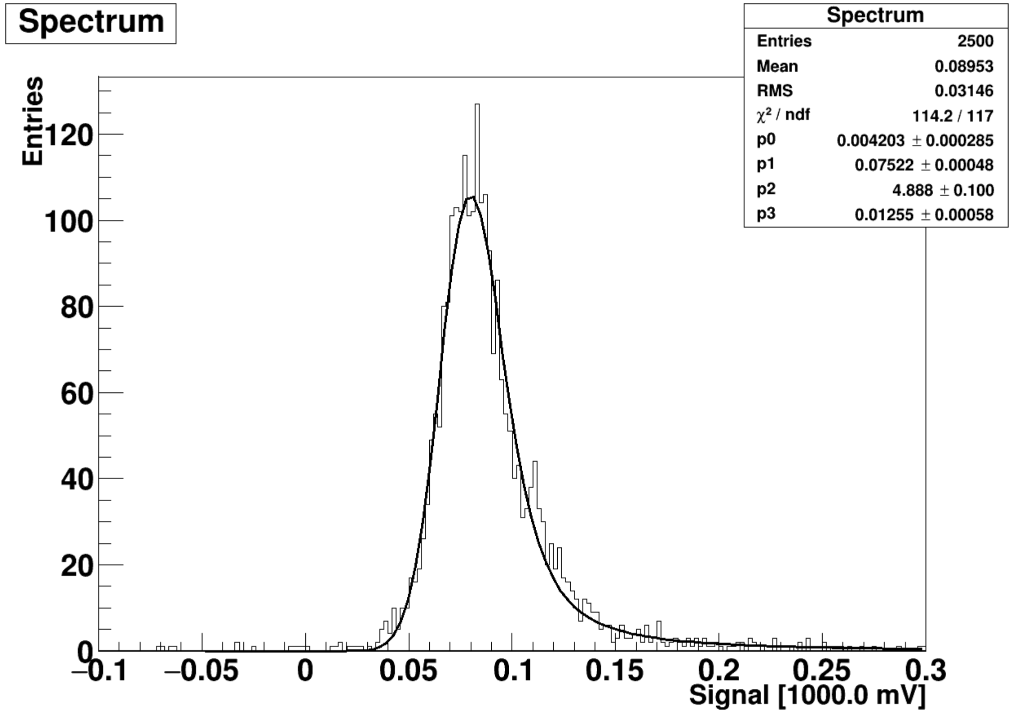
- charge collection from the top 50 µm of the structure
  ➔ high electric field in the substrate not observed also after 3e17 n/cm^2

Very preliminary measurements, unusual effects observed ➔ systematic studies needed!

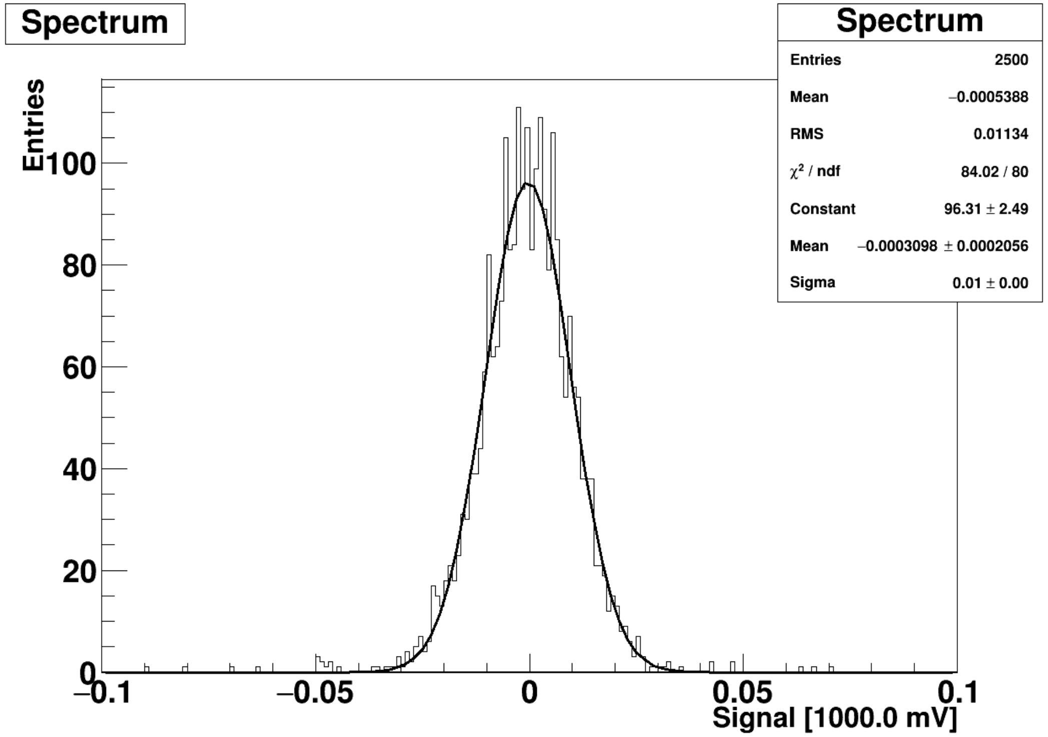
Charge collection measurement with Sr-90

Calibrate modified amplifier with: Micron, p-type, 300 um thick, Bias = 100 V

➔ looks ok



MPV = 75 mV (~ 24000 el)



Noise (RMS of the distribution) ~ 10 mV (~ 3000 el)